

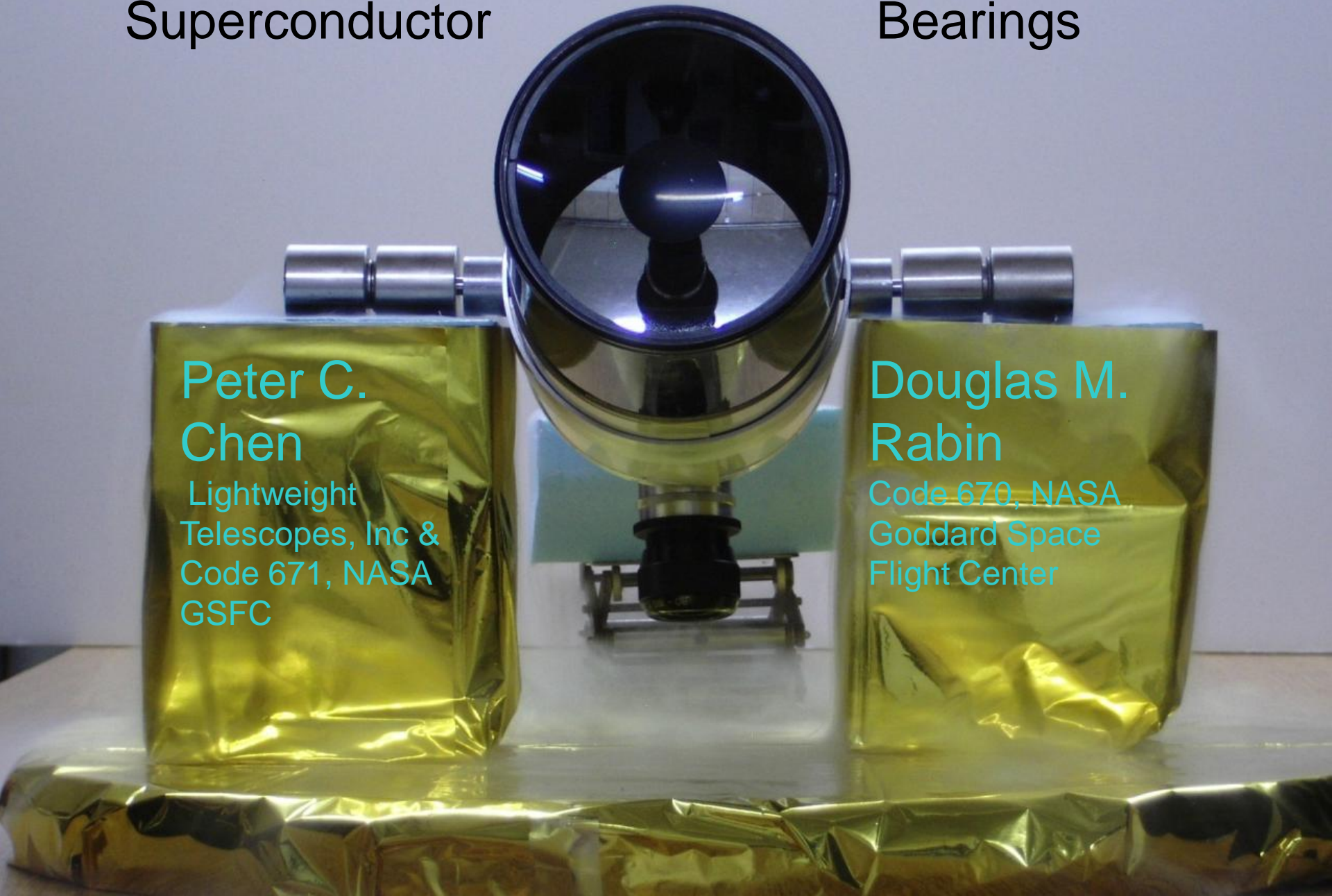
Building a Prototype Lunar Telescope with Superconductor Bearings

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Abstract

We report on the status of a prototype lunar telescope currently under construction. The telescope, which uses high temperature superconductor bearings, is intended as a tool for education and public outreach.

Telescopes and other pointing instruments on the Moon require extremely precise pointing systems that can function in the lunar environment. High temperature superconductor bearings are uniquely suited for such applications.

Working In The Lunar Environment

On the Moon the nights are long (15 days) and temperatures range from 100K to 30K inside shadowed craters. Pointing instruments on the Moon therefore require bearing systems that can position and track precisely over long time periods, with no maintenance and do not fail with loss of power.

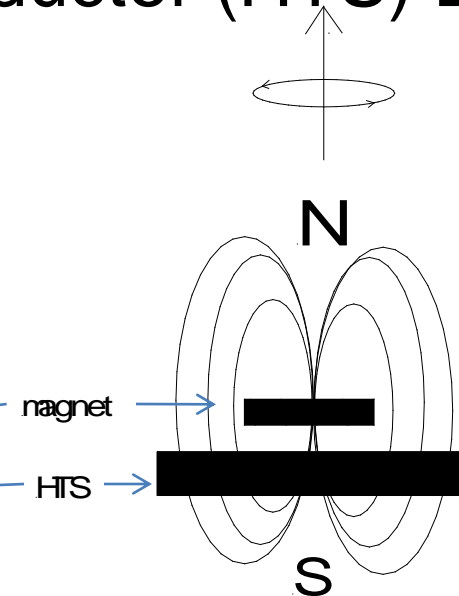
Normal mechanical bearings and lubricants do not function well under these conditions.

In addition to telescopes, many other devices have the same or similar requirements. These devices range in size from decimeters (laser communication systems) to meters (communication dishes, optical interferometers, solar panels) to decameters and beyond (VLA type radio interferometers).

High Temperature Superconductor (HTS) Bearings



Left: Sisters Hannah and Sarah Keyes having fun with levitation and flux pinning of a magnet by a high temperature superconductor (HTS).



A HTS bearing consists of a permanent magnet and a high T_c bulk superconductor. A unique phenomenon known as 'flux pinning' attaches the two together, almost physically but without contact. The system is passive and has no wear. If the magnetic field has rotational symmetry the magnet can turn freely about its axis of symmetry. This is the basis for HTS bearings

Scaling Problem in a HTS Alt-Az Mount

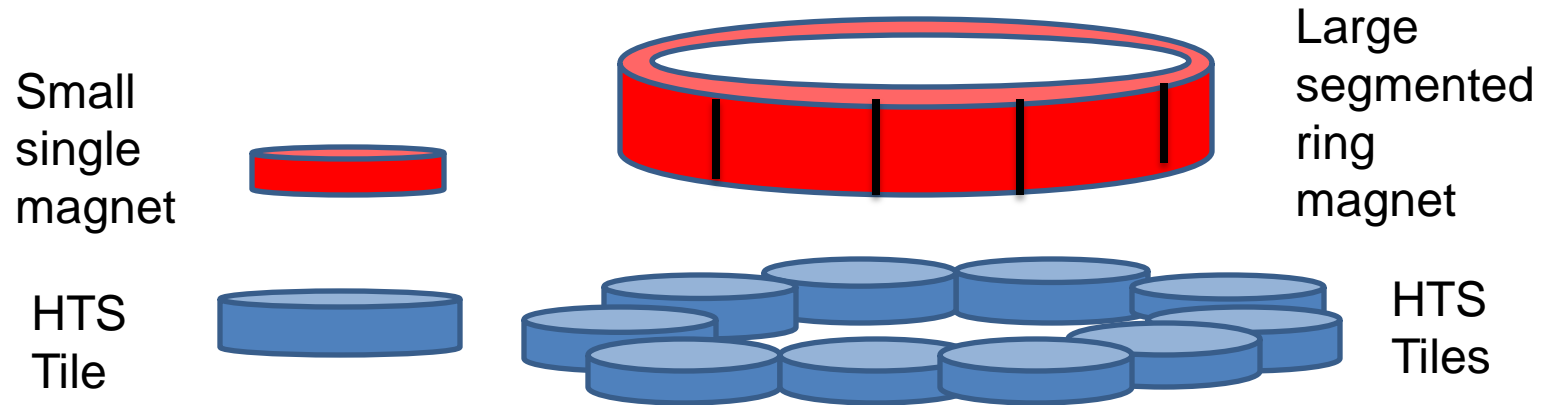


Fig. A. Small Bearing System

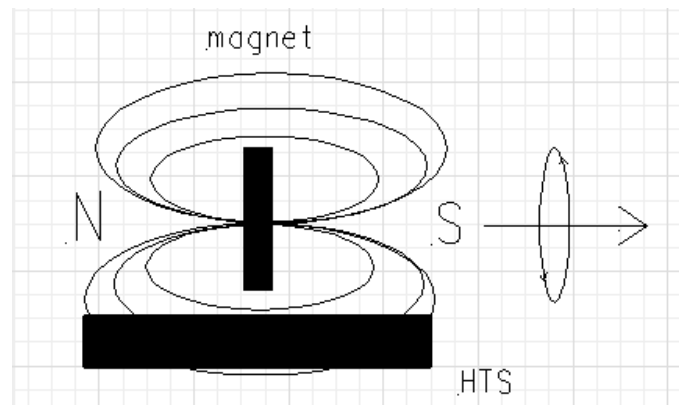
Fig. B. Large Bearing System

It is not practical to use HTS bearings in the customary alt-az (altitude-azimuth) and equatorial mount configurations. The problem is scaling.

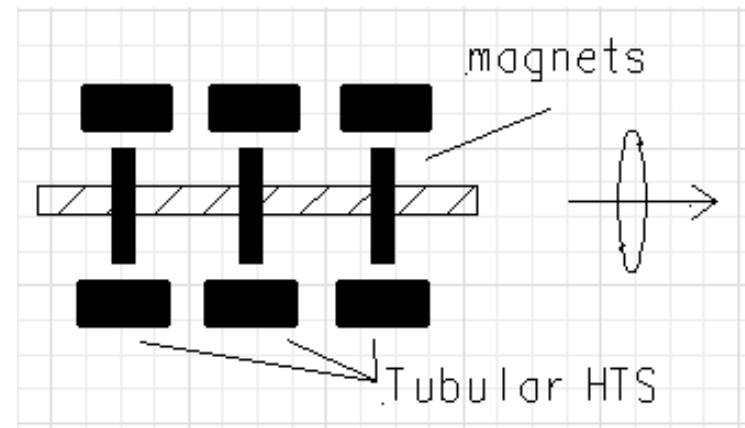
A levitated magnet can spin freely only if the HTS does not sense any change in field while the magnet rotates (fig. A). For supporting large loads, large area ring magnets are needed. Large magnets can only be made in segments (fig. B). The joints between segments introduce discontinuities in the magnetic field and cause cogging and/or jitter in the rotary motion.

Our Idea

Use HTS Bearing with Horizontal Axis of Rotation



A magnet with a horizontal magnetic axis can rotate freely above a HTS base



HTS bearings with horizontal axes can increase load capacity by joining multiple units on a longer axle. The process can be extended indefinitely without introducing discontinuities in the magnet field.

Available Types of Superconductors

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<u>Transition Temp (K)</u>	<u>Material</u>	<u>Class</u>
135	HgBa ₂ Ca ₂ Cu ₃ O _x	Copper-oxide superconductors
110	Bi ₂ Sr ₂ Ca ₂ Cu ₃ O ₁₀ (BSCCO)	
92	<u>YBa₂Cu₃O₇ (YBCO)</u>	
77	Boiling point of Liquid nitrogen	
55	SmFeAs(O,F)	Iron-based superconductors
41	CeFeAs(O,F)	
39	MgB ₂	
27	SrFe ₂ As _{1.3} P _{0.7}	
26	LaFeAs(O,F)	
20	Boiling point of liquid hydrogen	
18	Nb ₃ Sn	Metallic low-temperature superconductors
10	<u>NbTi</u>	
4.2	Hg (<u>mercury</u>)	

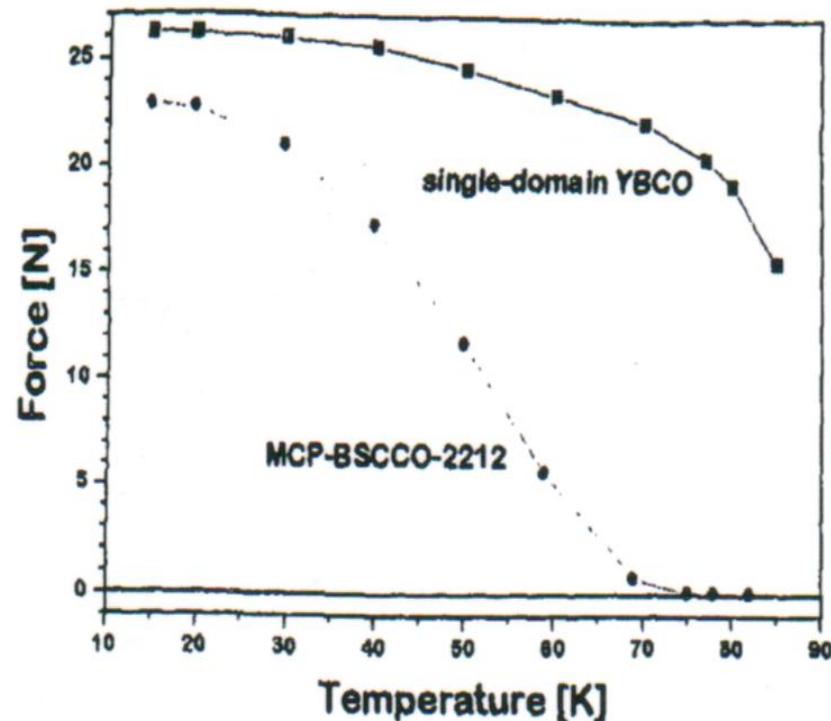
For general applications on the Moon, the viable candidate superconductors are YBCO and BSCCO.

Source: http://en.wikipedia.org/wiki/High-temperature_superconductivity,
<http://iopscience.iop.org/0953-8984/22/12/125702.jsessionid=68D7F12045778CE2D6032D6F66418F17.c3>,
 Collins, G. (2009) 'An iron key to high-temperature superconductivity?' Sc. Am. Aug. 62-69

Selection of High T_c Superconductors: YBCO vs BSCCO

Temperature dependence of F_z of 30mm diameter cylinders of TSMG YBCO and MCP BSCCO at 5 mm gap.

(Source: Gauss et al. (1999)
'Cryotank with superconducting, magnetic suspension of the interior tank', IEEE Appl. Supercon. 9, No.2, June 1999, 1004-1007)

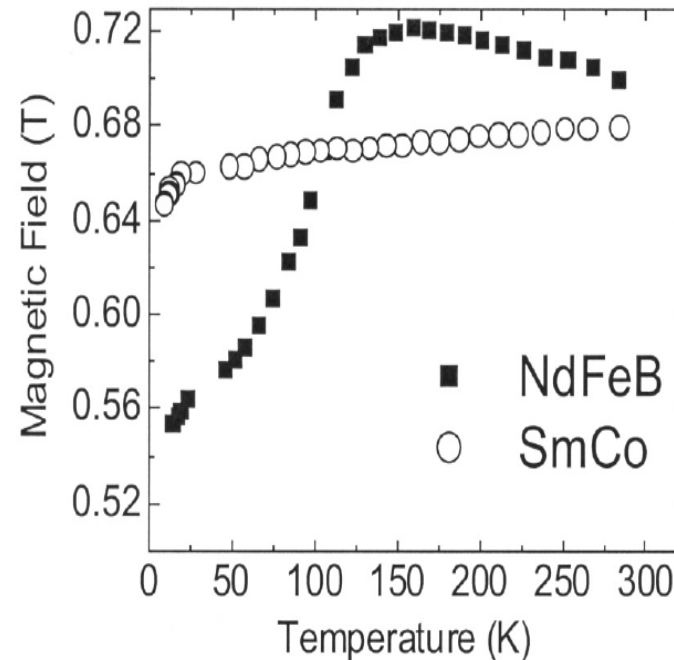


The performance (in terms of levitation force) of YBCO is superior to that of BSCCO at temperatures encountered on the Moon, except possibly within permanently shadowed craters.

Selection of Magnets: NdFeB vs SmCo

Magnetic Field as Function of Temperature for NdFeB and SmCo permanent magnets.

(Source: *High and Low Temperature Properties of Sintered Nd-Fe-B Magnets*, K.J. Strnat, D. Li, and H. Mildrum, Paper no. VIII-8 at the 8th International Workshop on Rare Earth Magnets and Their Applications, Dayton, OH, 6-8 May, 1985)



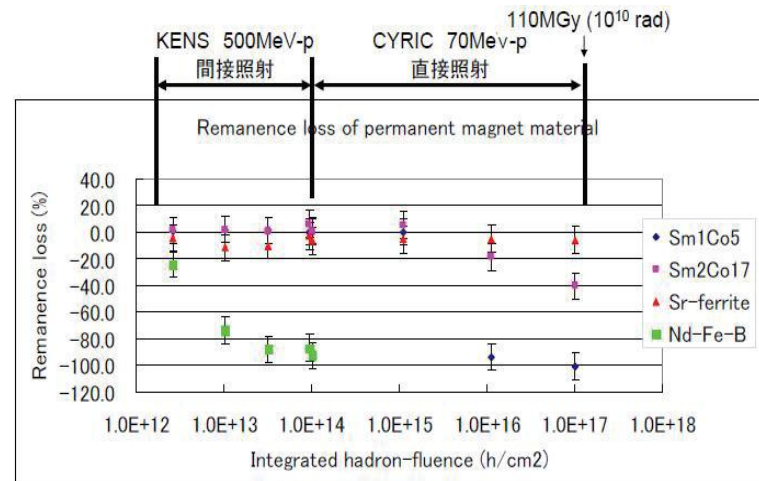
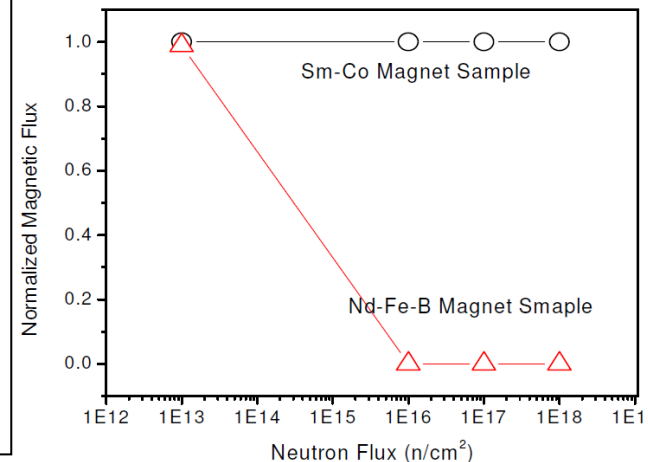
The strongest magnets available are of two types: neodymium iron boron (NdFeB) and samarium cobalt (SmCo). The figure shows how their magnetic fields vary as a function of temperature.

Radiation Sensitivity of NdFeB and SmCo Magnets

It is well known among physicists that NdFeB and SmCo magnets differ greatly in how they are affected by radiation. The two figures show the effects of neutron flux (top) and proton radiation (bottom).

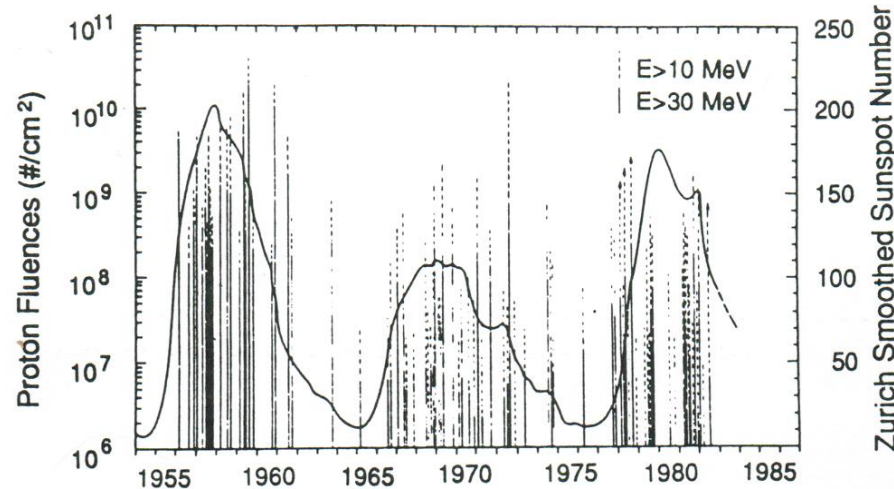
Normalized Magnetic Flux of Permanent Magnets versus Neutron Flux.

(Source: Liu, J. Vora, P., Walmer, M., Chen, C., Talnagi, J., Wu, S., and Harmer, M. THERMAL STABILITY AND RADIATION RESISTANCE OF SM-CO BASED Permanent Magnets, Proceedings of Space Nuclear Conference 2007 Boston, Massachusetts, June 24-28 2007, paper 2036.



Remanence loss in SmCo and NdFeB magnets under proton irradiation. (Source: Y. Sato et. al. (2007) *A RADIATION DAMAGE TEST OF PERMANENT MAGNET MATERIALS FOR RESIDUAL GAS IONIZATION PROFILE MONITORS*. Proceedings of the 4th Annual Meeting of Particle Accelerator Society of Japan August 1-3, 2007, Wako Japan)

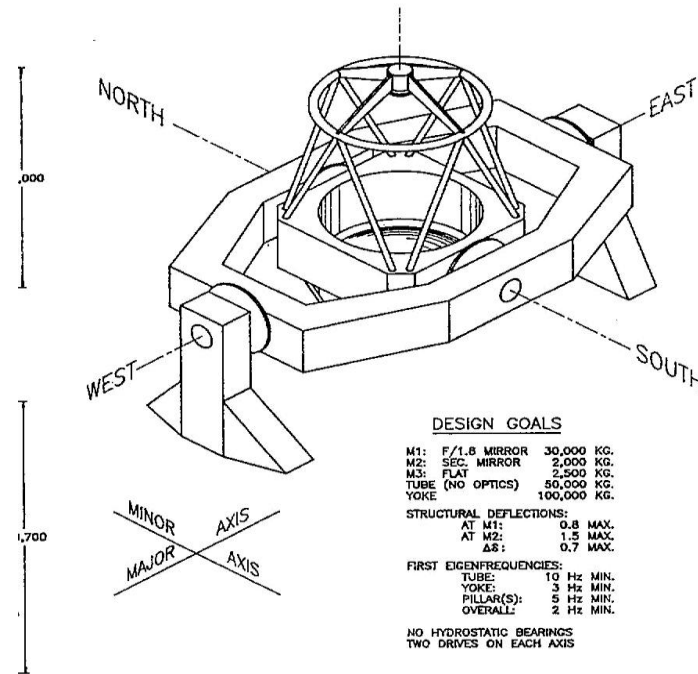
Radiation Environment on the Moon



Proton fluence above 10 Mev and 30 Mev in solar flares during three solar cycles. Source: Johnson, C.L. and Dietz, K.L. (1991) Effects of the lunar environment on optical telescopes and instruments, Proc. SPIE 1494 Space Astronomical Telescopes and Instruments (1991), 208-218.

As shown in the previous slide, SmCo has higher radiation resistance. However, in the lunar environment the level of radiation, in terms of particle flux and particle energy distribution, is below the level where the difference between NdFeB and SmCo becomes significant. YBCO, with its higher ratio of maximum field strength to mass, is therefore the preferred candidate.

Using HTS Bearings In Large Telescopes

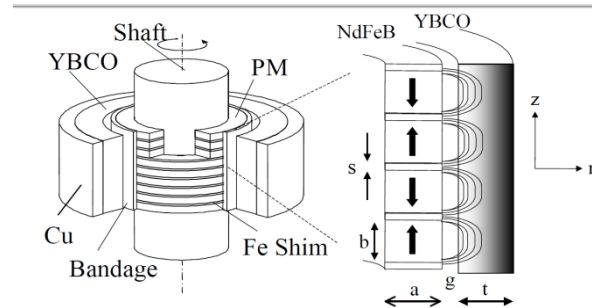


A telescope mount that uses bearings with horizontal axes ('trunion bearings') is the altitude-altitude (alt-alt) design. This concept has been studied in the past, but has not seen much use because the tracking is in two directions and therefore impractical until the advent of computer control. The drawing shown is a design by Richardson et al. for a 8m ground telescope. The four bearings, which are driven together, are located at the cardinal points E-W-N-S.

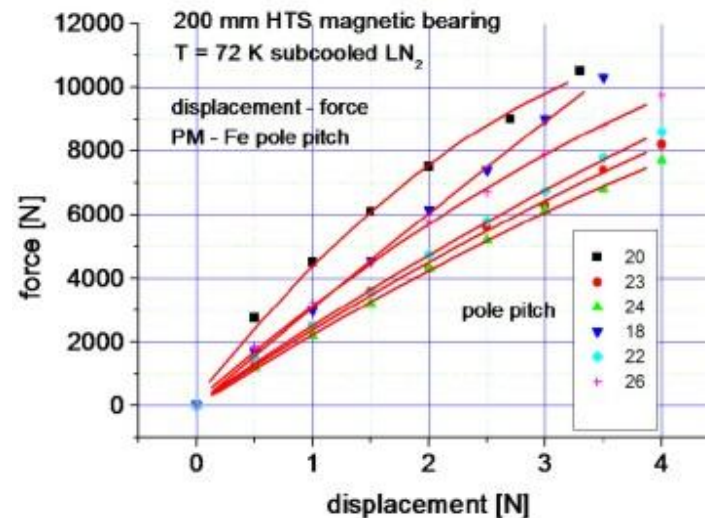
Ref: Richardson, E.H., Grundmann, W.A. & Odgers, G.J. (1990) "Altitude-altitude (alt-alt) mounting for an 8-metre telescope", Proc. SPIE 1236, 896-900.

Optimum Spacing and Magnet Field Configuration in a HTS Bearing

A. Construction of a commercial HTS bearing (Werfer et. al.)



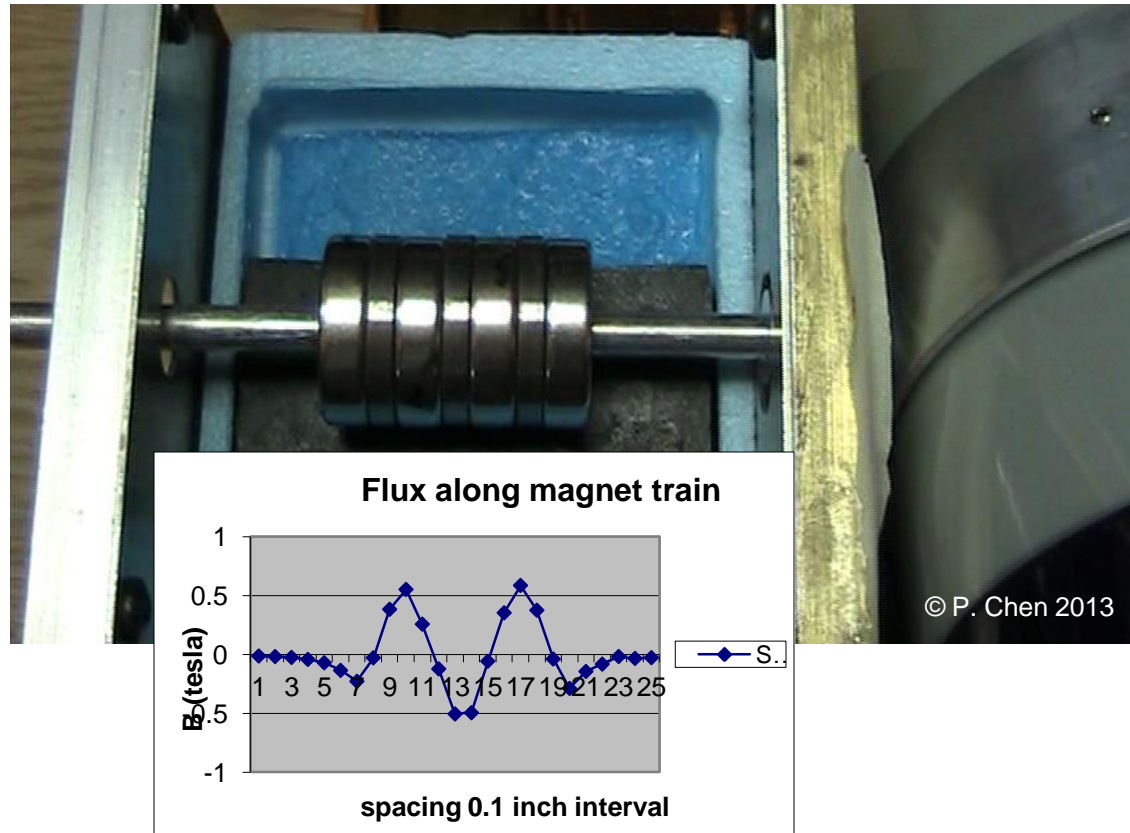
B. Measurement of the force between HTS and permanent magnet as a function of their separation distance. (Werfel et. al.)



Levitation force in a HTS bearing system is a function of the magnetic flux and the flux gradient. Maximum force is obtained in a string of magnets separated by iron shims (fig. A). (Source: Werfer, F., Floegel, U., Riedel, T., Rothfeld, R., Wippich, D. and Goebel, B. (2009) HTS Magnetic Bearings in Prototype Application, publ. MT-21-INV—09-0171(1FO-01), ATZ GmbH, Adelwitz, Germany.

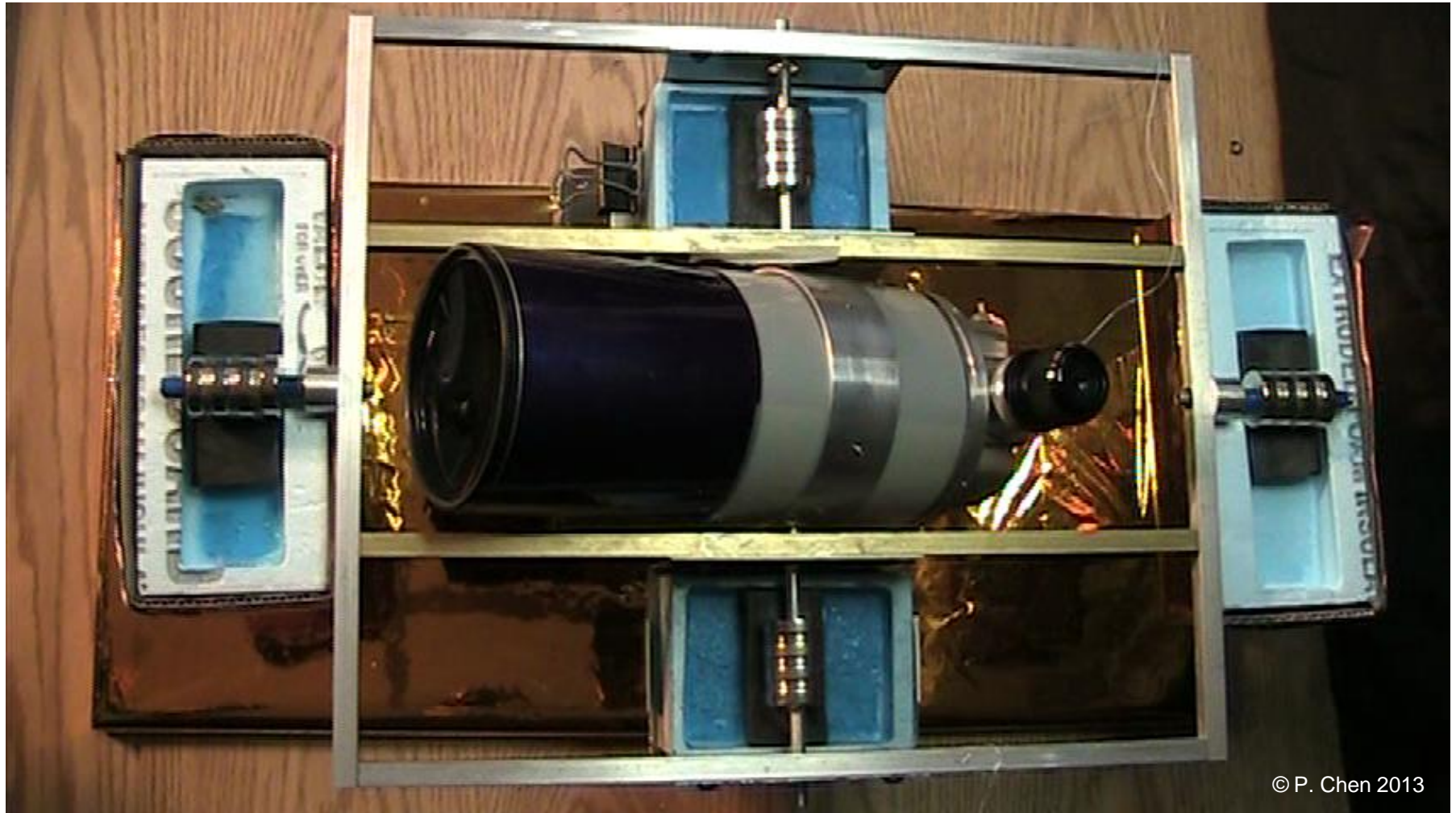
Lunar HTS Telescope Bearing Detail

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The upper picture shows a foam box (blue) containing a YBCO HTS tile (black rectangle) and one set of bearings. Each bearing set consists of four NeFeB permanent magnets separated by three iron spacers. The chart shows the variation of B measured by a Hall Probe Magnetometer along its length.

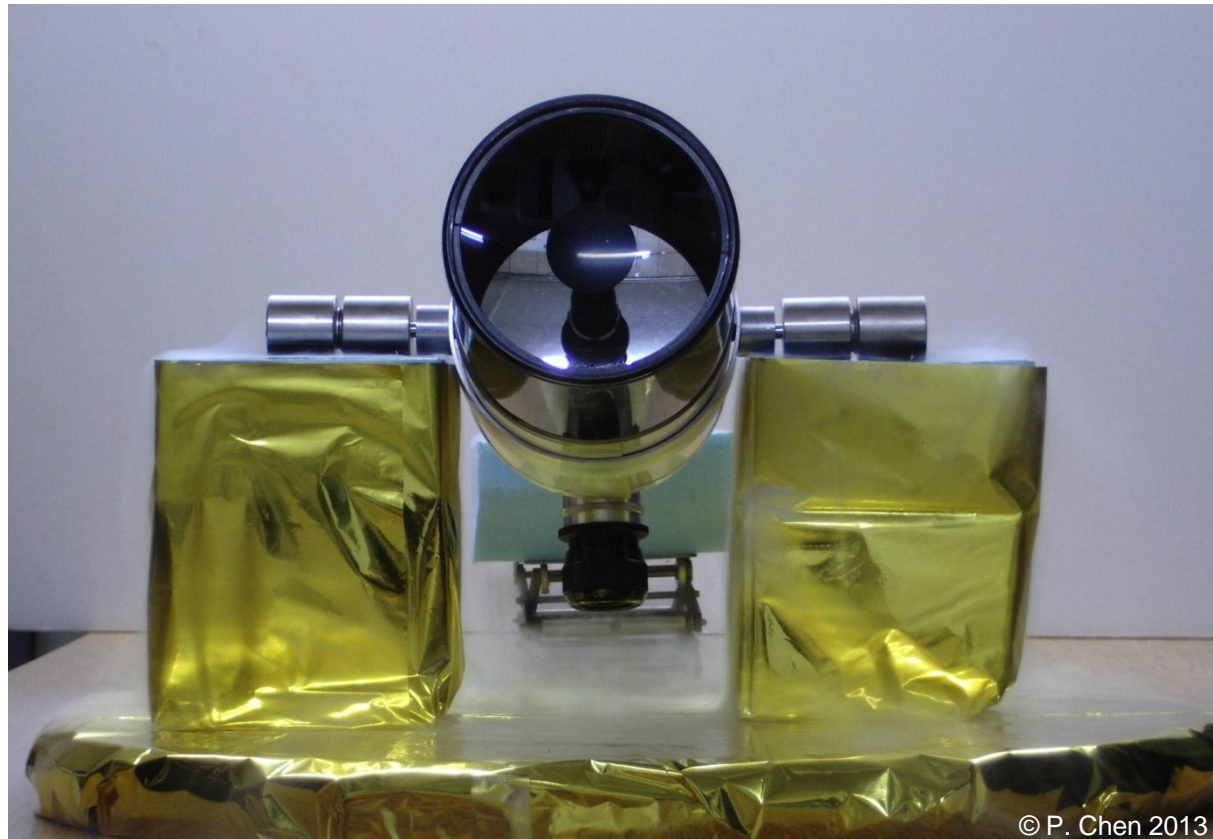
Model Lunar Telescope with Superconductor Bearings



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We are building a model telescope with HTS bearings in an altitude-altitude mounting. The telescope swings up and down on two bearings on its sides (vertical in the picture). It moves side-to-side on two bearings (horizontal in the picture) located at the front and rear.

Model Lunar HTS Telescope Levitated On Upper Stage



Shown above is the Questar® telescope being levitated on one set of its bearings. This is the upper stage bearing which permits the telescope to point up and down.

Model Lunar HTS Telescope Levitated On Lower Stage



The picture shows the Questar® telescope being levitated on the other set of its bearings. This is the lower stage bearing which permits the telescope and the structure holding it to swing from side to side.



Artist's concept of a large telescope on the Moon using HTS bearings

Background: NHK TV Japan. Artwork by Alan Chen (RPI) and Heather Chen (St. Mary's College MD)

Work In Progress

Work is currently under way in the following areas:

1. The HTS bearing is essentially frictionless. Fine adjustment mechanisms are being designed and incorporated so that components of the telescope can be precisely positioned and balanced.
2. A non-contact drive system is being designed that can move the telescope without making physical contact.
3. Advanced CAD (computer aided design) tools are being used to design and build an improved model.

Acknowledgements

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